Charmonium in Medium and at RHIC

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Abstract. The production of charmonia in relativistic heavy-ion collisions is formulated within the framework of a quantum kinetic theory simultaneously accounting for breakup and recombination processes. The survival probability of J/ψ mesons is evaluated for a Mott-Hagedorn resonance gas, whereby the pattern of anomalous J/ψ suppression at CERN-SPS can be explained by a strong coupling to open-charm states and their in-medium modification. Recent data for charmonium suppression from *Au-Au* collisions at RHIC are discussed.

Keywords: J/ψ suppression, Lattice QCD, sQGP, Mott effect, Hagedorn resonances, RHIC
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INTRODUCTION

Recent experiments at RHIC have revealed that the quark-gluon plasma in the vicinity of the QCD phase transition is strongly correlated (sQGP) with a low viscosity (perfect liquid), see [1] for a recent review. It has been conjectured that this result of a flow data analysis might be due to the presence of hadronic bound states [2] or resonances [3] above the critical temperature T_c for the phase transition. The persistence of hadronic correlations above T_c has been obtained before in lattice QCD simulations. Since the steep increase of the effective number of degrees of freedom which defines T_c as seen in lattice data for the energy density ε/T^4 could nicely be understood in terms of the Hagedorn resonance gas [4], the question appeared whether the QCD thermodynamics even above T_c could be interpreted in terms of hadronic degrees of freedom. Assuming a spectral broadening of the hadrons due to a Mott transition an alternative interpretation of the lattice data has been given [5]. The key element of a microscopic formulation of such a Mott-Hagedorn resonance gas is the description of the Mott transition for hadrons in hot and dense matter in terms of the hadronic spectral functions. First steps in this direction and possible consequences for the behavior of charmonium states in the sQGP at RHIC will be discussed in this contribution.

CHARMONIUM KINETICS IN THE SQGP

According to the above picture of the sQGP as being composed of strong hadronic correlations at a large phase space density, a huge number of energetically degenerate decompositions in terms of a hadronic basis emerges which are related to each other by flipping the string-type interaction links between quark-antiquark pairs. The left two panels of Fig. 1 give an example for such a string-flip process actually involving four pairs. At each time step the system has strong nearest neighbor correlations resulting in

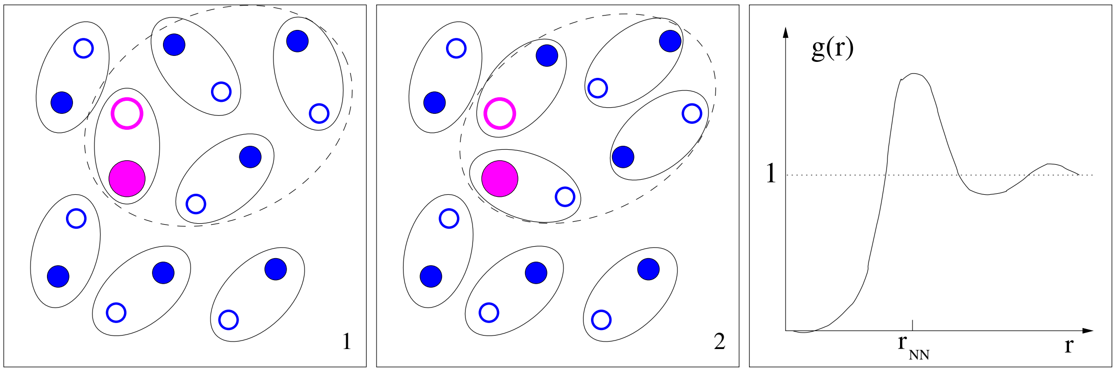

FIGURE 1. Hadronic correlations in quark matter depicted by encircling pairs of quarks (full dots) and antiquarks (open dots). A rearrangement collision (string-flip process) relates the left and middle panels. The right panel illustrates the liquid-like pair correlation function with a nearest-neighbor peak.

a liquid-like pair correlation function, see Fig. 1 (right panel). The string-flip processes may occur at a high rate leading to a sizeable spectral broadening of all hadronic basis states in accordance with the Mott-Hagedorn resonance gas picture which provides a physical understanding for phenomena like fast chemical equilibration and anomalous J/ψ suppression. The suppression of the production of charmonia states at increasing the energy density in a heavy ion collision has been suggested as an indicator for QGP formation on the basis of a simple argument: the charmonia states obtained as solutions of the two-particle Schrödinger equation for a temperature- dependent heavy-quark potential from lattice-QCD show a Mott-transition of the J/ψ bound state to the continuum of scattering states at $T \sim 1.2\ T_c$, see [6] and Refs. therein. This picture, however, is not appropriate for the situation of the sQGP where the medium consists of strongly correlated quarks in hadronic resonance states. The dominant process leading to J/ψ suppression is then a quark rearrangement collision (string-flip) process [7, 8] corresponding to charmonium dissociation into open charm states, see Fig. 2. It has been shown that this process, which in the vacuum and at temperatures below T_c is suppressed by a reaction threshold of ~ 600 MeV, becomes critically enhanced at the chiral phase transition since the open charm mesons undergo a Mott-like transition with a spectral broadening effectively lowering the charm dissociation threshold [9, 10]. The proper quantum kinetic formulation of the problem of heavy quarkonia states in the

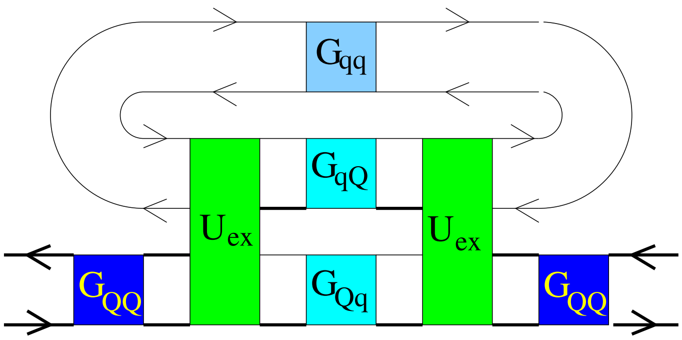

FIGURE 2. Quark rearrangement (string-flip) couples heavy and light quarkonia to heavy mesons.

sQGP can be given along the lines of the Kadanoff-Baym equation approach, where the propagators of the composite states in the quark rearrangement process are obtained from solutions of the Bethe-Salpeter equations for the corresponding T-matrices [11], see Fig. 2. The momentum-dependent lifetime $\tau_{Q\bar{Q}}(p)$ of the charmonia states is given by

$$\tau^{-1}_{Q\bar{Q}}(p) = \Sigma^{>}_{Q\bar{Q}}(p) - \Sigma^{<}_{Q\bar{Q}}(p) \, , \tag{1}$$

$$\Sigma^{\gtrless}_{Q\bar{Q}}(p) = \int\limits_{p'}\int\limits_{p_1}\int\limits_{p_2} (2\pi)^4 \delta_{p,p';p_1,p_2} \, |U_{ex}|^2 \, G^{\lessgtr}_{q\bar{q}}(p') \, G^{\gtrless}_{q\bar{Q}}(p_1) \, G^{\gtrless}_{Q\bar{q}}(p_2) \, , \tag{2}$$

where $\Sigma^{>}_{Q\bar{Q}}(p)$ ($\Sigma^{<}_{Q\bar{Q}}(p)$) stand for the effect of loss (gain) processes and depend on the hadronic Green functions $G^{>}_{i}(p) = [1 + f_i(p)]A_i(p)$ and $G^{<}_{i}(p) = f_i(p)A_i(p)$ defined by their spectral functions A_i and phase space occupation functions f_i, where $i = q\bar{Q}, Q\bar{q}, q\bar{q}$. Within this approach the observed saturation of the anomalous J/ψ suppression in recent RHIC experiments is explained by the detailed balance between gain and loss processes when the charm meson phase space is sufficiently populated.

CONCLUSIONS

A microscopic formulation of the QCD phase transition is suggested in terms of a hadronic basis with the Hagedorn mass spectrum and a spectral broadening due to frequent quark rearrangement processes in a hot and dense medium (Mott dissociation). the approach provides a simultaneous understanding of Lattice QCD thermodynamics, hadronic correlations above T_c, anomalous J/ψ suppression at CERN-SPS and its saturation at RHIC experiments.

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